Experimental Material Characterization for Mechanical Properties Validation for 304L Stainless Steel

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Abstract

This graduate project presents an experimental characterization of the mechanical properties of aerospace-grade 304L stainless steel plate. Non-welded base-metal specimens and TIG-welded specimens were prepared and tested in accordance with ASTM E8 at room temperature and under simulated cryogenic conditions achieved through CO_2 cooling. The investigation focused on yield strength, ultimate tensile strength, and elongation, with particular attention to the effects of welding and low-temperature exposure. Austenitic stainless steels such as 304L are widely used in cryogenic applications because they retain excellent ductility at very low temperatures. The results obtained in the PUPR Materials Laboratory provide original laboratory data that support quality-assurance practices for safety-critical components such as cryogenic propellant tanks and hydraulic systems in aerospace systems.

Introduction

This graduate project presents an experimental characterization of the mechanical properties of aerospace-grade 304L stainless steel plate. Non-welded base-metal specimens and TIG-welded specimens were prepared and tested in accordance with ASTM E8 at room temperature and under simulated cryogenic conditions achieved through CO_2 cooling. The study focuses on yield strength, ultimate tensile strength, and elongation, with particular attention to the effects of welding and low-temperature exposure.

Background

Stainless steel 304L is widely used in aerospace for cryogenic propellant tanks, hydraulic tubing, fasteners, and piping systems due to its excellent corrosion resistance, weldability, and performance at very low temperatures. Austenitic stainless steels such as 304L retain excellent ductility at cryogenic conditions, unlike ferritic or martensitic grades. Standards such as ASTM A240/A240M define minimum mechanical properties, yet real-world variability exists due to processing differences among suppliers.

Problem

A common challenge in the aerospace supply chain is the lack of independent verification of supplier-provided Material Test Reports (MTRs). Even when materials comply with standards, mechanical properties can vary significantly between lots. This study addresses this issue by performing independent tensile testing on both non-welded and TIG-welded specimens to quantify deviations and validate material performance under room-temperature and simulated cryogenic conditions.

Methodology

- Specimens machined from 1/8-inch 304L plate (non-welded and TIG-welded with ER308L filler).
- Gauge length 2 inches per ASTM E8.
- Tensile testing on ATS universal machine at 0.100 in/min crosshead speed.
- Simulated cryogenic conditions using CO_2 fire extinguisher (−109 °F).
- Data processed in Excel to generate stress-strain curves.
- Microstructural analysis of weld zone at 10× and 20× magnification.

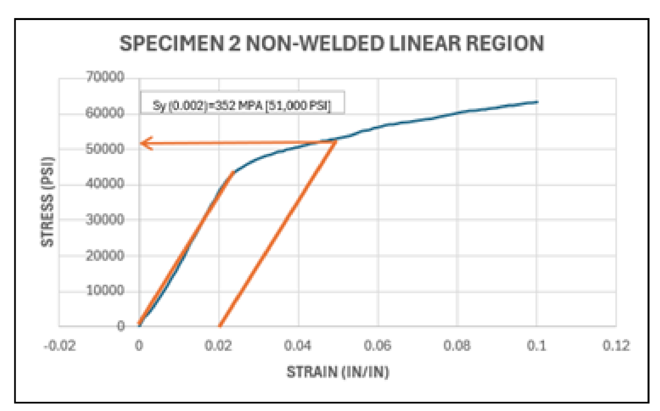

Figure 2
Non-Welded Stress-Strain Curve

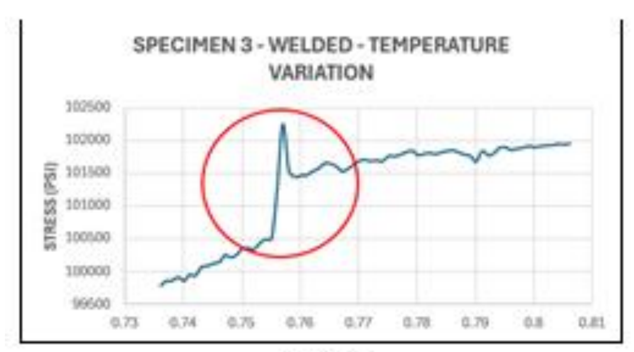

Figure 5
Welded Temperature Variation in the Plastic Region

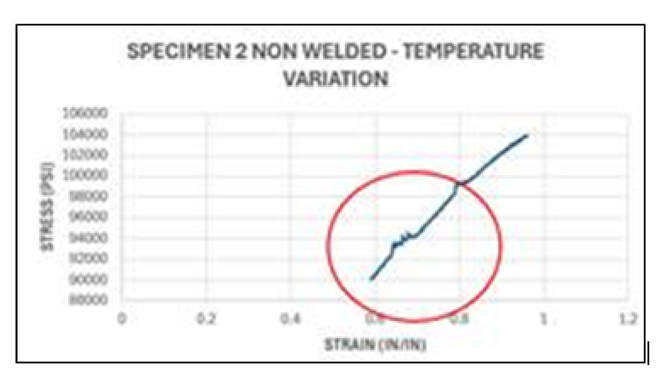

Figure 3
Non-Welded Temperature Variation in the Plastic Region

Figure 6
Before Fracture-Specimen at 10x

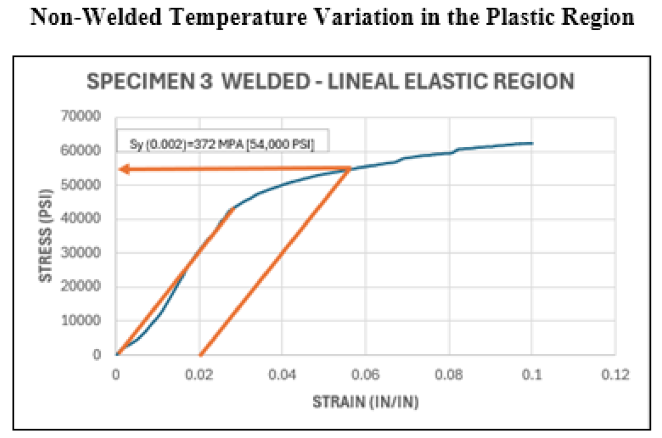

Figure 8
After Fracture-Specimen at 10x

Figure 9
Close-up of Fractured TIG Weld Zone

Results and Discussion

- Non-welded specimens showed ~2 inches elongation without fracture.
- Welded specimens exhibited slightly lower elongation due to localized stress concentration.
- CO_2 cooling produced measurable increases in yield strength (+12.9 %) and ultimate tensile strength (+10.7 %), with reduction in elongation (−24.6 %).
- Stress-strain curves confirm strengthening in the plastic region.
- Microstructure shows sound fusion with no significant defects.
- Results consistent with expected cryogenic behavior of austenitic stainless steels (TRIP effect).

Table 1
Summary of Experimental Mechanical Properties of 304L

Property	Room Temperature	CO2 Cooled (-109 °F)	Change due to Cooling
Yield Strength (MPa)	202 +/- 3.2	228 +/- 4.1	12.90%
Ultimate Tensile Strength	522 +/- 4.1	578 +/- 5.3	10.70%
Elongation (%)	43.5 +/- 1.8	32.8 +/- 2.1	-24.60%

Figure 1
ATS Universal Tension Test Machine in the PUPR Mechanical Engineering Materials Laboratory

Conclusions

The experimental work successfully characterized 304L stainless steel at room temperature. Observable variations were noted under simulated cryogenic conditions. Although the work does not allow us to reach a formal conclusion due to the lack of specific equipment, it does show changes in the behavior that are in agreement with those observed in other experiments and with what is proposed as the hypothesis. The material lot is suitable for safety-critical aerospace components at room temperature. Welding and low-temperature exposure did not compromise the intrinsic mechanical properties.

Future Work

- Perform true cryogenic tensile testing using liquid nitrogen (−196 °C) per ASTM E8/E8M and ASME Section VIII.
- Evaluate additional supplier lots to quantify variability.
- Investigate fatigue and fracture toughness under combined welding and cryogenic conditions.

Acknowledgements

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References

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